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Distribution of Hourly Precipitation in Illinois

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SUMMARY AND CONCLUSIONS

A study was made of the annual, seasonal, geographic, and diurnal distribution of hourly precipitation in Illinois. It was found that the maximum number of rainy hours occurs in spring, except in the extreme southern part of the state where winter dominates. The minimum frequency changes gradually from fall to summer from the northern to the southern part of the state. Annually, extreme southern Illinois is the wettest region of the state, based on the frequency of hours with measurable precipitation.

With respect to precipitation intensity, hourly amounts in the range from 0.01 to 0.10 inch predominate in all seasons and account for over 80 percent of the annual occurrences in the state. Geographically, the annual percentage decreases from approximately 85 percent in the northern part of the state to 78 percent in the southern part. Conversely, the frequency of hourly amounts in the range from 0.11 to 1.00 inch increases from north to south, and the exceptionally heavy intensities, those in excess of 1 inch per hour, show no distinct geographic preference. As one would expect, the hourly intensities are highest in summer and lowest in winter.

Investigation was made of the diurnal distribution of total precipitation on a seasonal and annual basis. Except for winter in the northern half of the state, a well-defined minimum is shown in the diurnal distribution. This minimum occurs in late forenoon or early afternoon in all seasons and regions, except summer in the extreme south where the minimum occurs in the evening and early morning. The diurnal maximum is not as well-defined as the minimum. Except for summer in the extreme south, the primary maximum occurs during the night or early forenoon, and in the warm season, there is a secondary maximum in late afternoon or evening. In the extreme south in summer, the primary and secondary maximums are reversed, the primary occurring in the afternoon. These findings indicate the presence of a

nocturnal intensifying mechanism throughout the year over the state, and, except for the extreme south in summer, this mechanism exerts a greater influence on the diurnal distribution of total precipitation than does the daytime heating effect. During summer in the extreme southern part of the state, thermally induced convection from solar heating of the surface is a more important mechanism than the unexplained nocturnal phenomenon, about which there are several theories but none having widespread acceptance.

The diurnal distribution of the number of hours with measurable precipitation is similar, in most respects, to the total precipitation distribution. The diurnal effect upon the frequency of precipitation, indicated by actual and percentage differences between curve maximums and minimums, is greatest in winter in the extreme southern part of the state but shifts to the northwestern part in summer. The nocturnal thunderstorm phenomenon is more pronounced in the northwest in summer than in the rest of the state, and may be primarily responsible for the greater diurnal range of rainy hours. The frequency of frontal passages and the occurrence of convective precipitation are greater in the southern part than in the northern part of the state in winter, and may be related to the pronounced diurnal range in southern Illinois in winter. On an annual basis, the diurnal range is most pronounced in the extreme south where convective precipitation occurs frequently throughout the year and where the daytime heating exerts its greatest influence on the diurnal distribution.

Investigation was made of the intensity of precipitation on a diurnal basis. Results showed that light precipitation (0.01-0.10 inch per hour) accounts for most of the precipitation throughout the state, regardless of time of day. However, light precipitation is most dominant in late forenoon and early afternoon. Moderate hourly amounts (0.11-0.25 inch) have their highest percentage of the total fall in the early morning from 0300 to 0900 CST. Moderately heavy amounts (0.26-0.50 inch) exert their greatest influence on the diurnal distribution in late afternoon and early evening, except in the northwestern part of the state where late evening is more important. The heaviest amounts, those exceeding 0.50 inch, have their highest percentages in early to late evening over most of the state. In general, the heavy intensities tend to occur most frequently in late afternoon and evening, during and immediately following the period of maximum diurnal heating of the surface. Moderate amounts tend to be associated most frequently with the nocturnal maximum in the precipitation distribution.

Comparison of the curves of total precipitation, frequency of precipitation, and mean precipitation rate indicated that daytime heating has a strong influence on both the development and intensification of showers and thunderstorms in extreme southern Illinois in summer. In the South Central Section (see figure 1), the daytime heating effect appears to exert greater influence in the intensification of convective storms than in the development of air mass showers. In the North Central and Northwest Sections, daytime heating appears to have little effect in creating air mass showers in the absence of other instability influences, but it does result in the intensification of summer rainstorms.

A comparison was made between the diurnal distribution of frontal passages at Urbana and the diurnal distribution of precipitation hours in the North Central Section. Results suggest that the nocturnal maximums in the precipitation distributions may be partially explained by the diurnal distribution of fronts.

Investigation was made of the relation between the diurnal climatological distribution of precipitation, based on all precipitation occurrences, and the occurrence of severe rainstorms in Illinois. It was found that severe rainstorms with durations of 2k hours or less maximize almost exclusively at night and in the early morning (between 1800 and 0900 CST), based upon 3- and 6-hour periods of heaviest rainfall. The great skewness in the occurrence of severe rainstorms suggests that exposure of existing convective systems to both the daytime heating and nocturnal intensifying mechanisms may be a major cause of the preponderance of night and early morning maximums in these storms.

INTRODUCTION

This study of the distribution of hourly precipitation amounts was undertaken as part of a general program of climatological research to define in detail the time and space distribution of precipitation in Illinois for engineering and agricultural applications. Further, the hourly precipitation study provides information valuable in research of the State Water Survey concerning the meteorology of severe rainstorms in the state (Huff and Semonin, 1960).

The hourly precipitation study was based on data from 30 recording raingage stations in Illinois during the 10-year period 1948-1957. Analyses were made of the annual, seasonal, geographic, and diurnal distribution of hourly precipitation. These distributions were examined with respect to the amount, intensity, and frequency of occurrence of precipitation.

This report was prepared under the general supervision of Dr. William C. Ackermann, Chief of the Illinois State Water Survey, and G. E. Stout, Head of the Atmospheric Sciences Section. It was reviewed by Stanley A. Changnon, Jr., Acting Head of the Section, and by Mrs. J. Loreena Ivens, Technical Editor. Data which made this study possible were obtained from the National Records Center of the U. S. Weather Bureau at Asheville, North Carolina. Use of IBM and digital computer facilities at the University of Illinois greatly facilitated the analyses.

DATA AND ANALYTICAL PROCEDURE

The basic data employed in this study consisted of tabulations of hourly precipitation amounts from recording raingages as entered on IBM punch cards by the U. S. Weather Bureau (now National Weather Service). These data are available beginning with 1948, and include clock-hour amounts for each hour of each day on which measurable precipitation occurred. For this study, 30 stations in or near Illinois were selected for sampling the climatic regime of the state. The locations of these stations are shown in figure 1. Uniformity in distribution of the sampling stations was achieved to the extent permitted by the recording raingage network in the state.

As the first step in the study, an IBM machine sort of the data was made for each of the 30 stations. In this procedure, hourly precipitation amounts were grouped into several classes of intensity, and the number of occurrences were tabulated according to intensity for each hour of the day for each month of the year. The intensity classes included 0.01-0.10 inch, 0.11-0.25 inch, 0.26-0.50 inch, 0.51-1.00 inch, 1.01-2.00 inches, 2.01-3.00 inches, and over 3 inches. The printouts from the above tabulations provided the data for defining the diurnal, seasonal, and geographic distributions of hourly precipitation with respect to frequency of occurrence. A second IBM sorting was made to obtain the diurnal distribution of total precipitation, that is, the amount or percentage of all measurable

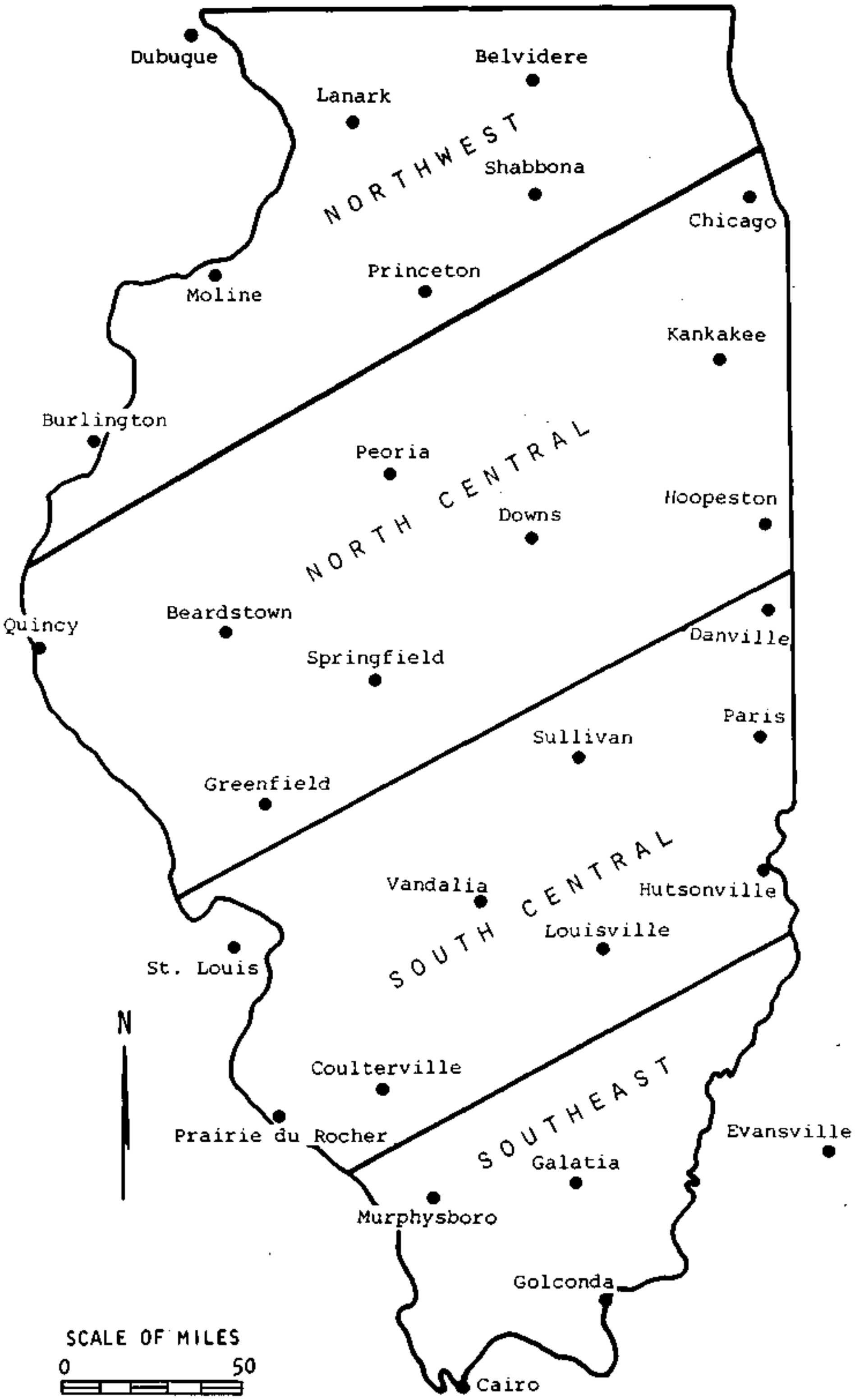

Figure 1. Recording vaingage stations and climatoZogical sections used in study

precipitation that occurs at different hours of the day. From the two sortings, the average intensity of hourly precipitation was determined on a seasonal, geographic, and diurnal basis.

The next step in the study was to divide the state into approximately homogeneous climatological sections for evaluation of the geographic distribution of hourly precipitation. Because of sampling errors imposed by the number of sampling points and length of record used in this study, it was felt that the number of sections should be limited to as few as possible without combining areas of obviously different rainfall climate. Several combinations of climatological sections were investigated, and it was decided to use the 4-section division of the state (figure 1) previously used by Huff and Neill (1959).

ANNUAL, SEASONAL, AND GEOGRAPHIC DISTRIBUTIONS

The annual, seasonal, and geographic distributions of hourly precipitation amounts, with respect to number of occurrences and intensity of precipitation, have been summarized in table 1. The average number of hours per year with measurable precipitation has been shown for each of the four climatological sections on a seasonal and annual basis. Winter is defined as the months of December through February, spring as March through May, summer as June through August, and fall as September through November. Also shown in table 1 is the percentage distribution of the hourly precipitation by intensity classes for each geographic and time group. For example, in the Northwest Section in summer, there is an average of 99 hours per year in which measurable precipitation is recorded. Of these 99 hours, 71.8 percent (71 hours) have hourly amounts ranging from 0.01 to 0.10 inch, compared with 16.4 percent of the hours with hourly amounts of 0.11 to 0.25 inch and 7.1 percent with 0.26 to 0.50 inch.

Table 1 indicates that the maximum number of rainy hours occurs in spring in all except the Southeast Section where winter has the most hours with measurable precipitation. The minimum frequency of rainy hours changes gradually from fall to summer from the northern to the southern part of the state. The North Central Section is the cross-over region with nearly equal minimum frequencies in summer and fall. Annually, the Southeast Section is the wettest region of the state based on the frequency of hours with measurable precipitation.

Table 1. Annual and Seasonal Distribution of Hourly Precipitation by Section

Period	Average number of hours per year	Percent of total hours with given hourly amounts (*inches*) 0.01-0.10	0.11-0.25	0.26-0.50	0.51-1.00	Over 1.00
Northwest Section						
Winter	127	93.4	5.6	0.8	0.1	0.1-
Spring	155	86.2	10.6	2.4	0.7	0.1
Summer	99	71.8	16.4	7.1	3.5	1.2
Fall	87	83.5	12.5	2.8	0.9	0.3
Annual	468	84.6	10.8	3.1	1.1	0.4
North Central Section						
Winter	135	90.7	7.6	1.2	0.3	0.1-
Spring	151	84.8	11.2	3.0	0.8	0.2
Summer	90	72.1	15.0	8.0	3.7	1.2
Fall	89	84.2	11.4	3.4	0.9	0.1
Annual	465	83.8	11.1	3.5	1.3	0.3
South Central Section						
Winter	126	84.9	11.7	2.3	0.8	0.3
Spring	137	81.6	13.6	3.5	1.1	0.2
Summer	79	72.4	15.1	7.3	3.9	1.3
Fall	94	78.2	15.6	4.6	1.3	0.3
Annual	436	80.0	13.8	4.1	1.6	0.5
Southeast Section						
Winter	189	82.3	13.1	3.6	0.8	0.2
Spring	146	77.6	15.5	5.2	1.4	0.3
Summer	83	71.7	15.6	7.8	3.9	1.0
Fall	104	76.2	16.5	5.5	1.5	0.3
Annual	522	78.0	14.9	5.1	1.6	0.4

With respect to precipitation intensity, hourly amounts in the range from 0.01 to 0.10 inch predominate in all seasons and account for over 80 percent of the annual occurrences in the state. Geographically, the annual percentage decreases from 84.6 percent in the northern part of the state to 78.0 in the southern part. Conversely, the frequency of intensities in the range from 0.11 to 1.00 inch increases from the Northwest to the Southeast Sections. The exceptionally heavy intensities, those in excess of 1.00 inch per hour, show no distinct geographic preference. Seasonally, as one would expect, the hourly intensities are highest in summer and lowest in winter. For example, in the North Central Section, 12.9 percent of the hours with measurable precipitation in summer have amounts exceeding 0.25 inch, compared with 1.6 percent in winter, 4.0 percent in spring, and 4.4 percent in fall.

For comparison purposes, the mean annual precipitation based on the 50-year period 1906-1955 is shown for each of the four sections in table 2. The mean annual precipitation gradually increases from the Northwest Section southward to the Southeast Section. The increase is slight from the Northwest to the North Central Section, then becomes more pronounced from the North Central to South Central Sections and from the South Central to Southeast Sections. Table 1 shows the highest frequency of hours with measurable precipitation in the Southeast Section where the mean annual precipitation is greatest, but it does not indicate a gradual north-south increase from section to section as in the case of mean annual precipitation. Hourly intensities, however, show a close association with mean annual precipitation. A combination of all hourly amounts exceeding 0.25 inch in the annual values of table 1 shows that the frequency increases slowly from 4.8 percent in the Northwest Section to 5.1 percent in the North Central Section, then increases more rapidly to 6.2 percent in the South Central Section and to 7.1 percent in the Southeast Section.

Table 2. Mean Annual Precipitation (1906-1955)

Section	Annual mean (*inches*)
Northwest	34.16
North Central	35.07
South Central	39.28
Southeast	43.69

DIURNAL DISTRIBUTIONS

Total Precipitation Distribution

In defining the diurnal distribution of hourly precipitation, analysis was made first on the distribution of total precipitation on a seasonal and annual basis. This phase of the study was undertaken to determine if precipitation tends to occur more frequently during certain periods of the day. A study by Huff and Semonin (1960) has shown that the severe flood-producing storms in Illinois usually yield their heaviest rainfall during the night. However, no previous attempt has been made to study in detail the diurnal distribution of total precipitation, which includes all measurable storm amounts. The diurnal distributions of precipitation-related events such as sleet, snow, glaze, thunderstorms, and hail in Illinois have been described previously (Changnon, 1968).

Figures 2-5 show the diurnal distributions of total precipitation recorded during the 10-year sampling period in each of the four climatological sections on a seasonal and annual basis. The curves show the average percentage of the total rainfall which occurred during the hour indicated on the abscissa. Sectional values were obtained from the combined totals of all stations in the given section and therefore represent average conditions for the section.

A well-defined diurnal minimum for all seasons, except winter in the Northwest and North Central Sections, is shown in figures 2-5. Except for summer in the Southeast Section, the minimum occurs in late forenoon or early afternoon in all sections and seasons. The same is true for the minimums in thunderstorms in Illinois (Changnon, 1968). In summer in the Southeast Section, the minimum amount of rainfall occurs during the evening and early morning hours.

The diurnal maximum of total precipitation is not as well-defined as the minimum in figures 2-5. In winter in the Northwest and North Central Sections diurnal variations are not great. The diurnal curves show a series of fluctuations of small amplitude with no dominating diurnal maximum. The diurnal variation in winter becomes quite pronounced in the South Central and Southeast Sections with maximization in the late evening and early morning hours when Changnon (1968) has shown that thunderstorms and snowfall are most frequent.

In spring, the Northwest, North Central, and Southeast Sections show a primary maximum at midnight and a secondary maximum in the early forenoon. The primary maximum at midnight also exists in thunderstorm frequencies (Changnon, 1968). The South Central Section exhibits a primary maximum at 0800 CST with minor peaks near 1800 and 2000 CST, probably reflecting the diurnal heating influence on the development of showers as the warm season is reached. A bulge in the curves of the other three sections appears in the late afternoon or early evening and also reflects the daytime heating influence.

The diurnal variations become very pronounced in all sections in summer. The Northwest, North Central, and South Central Sections show a primary maximum in the

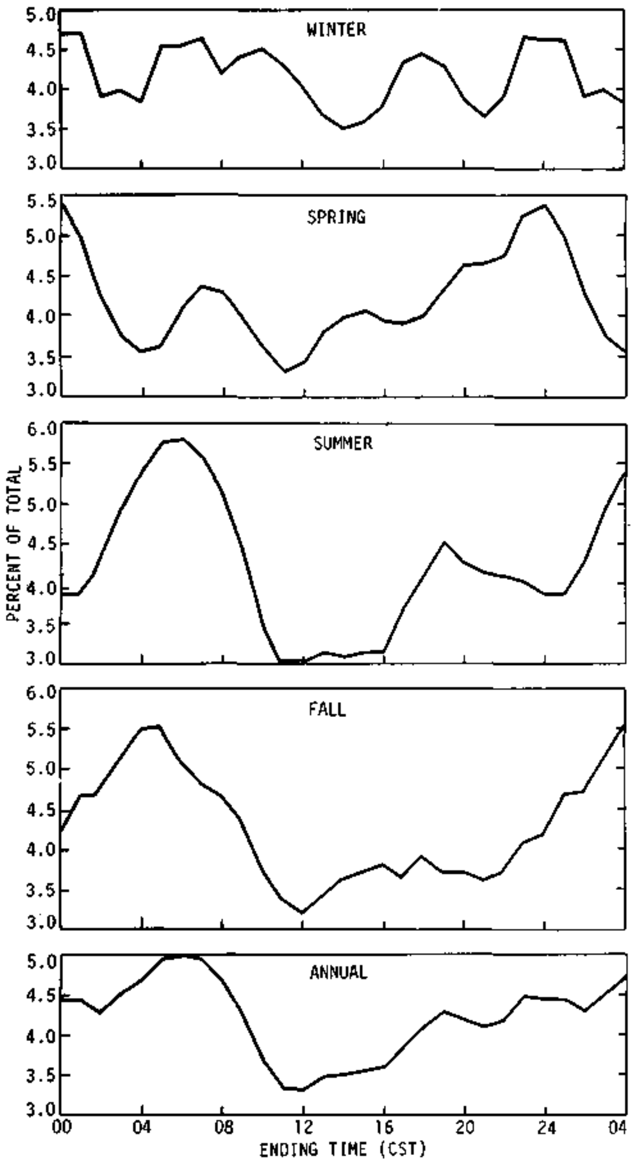

Figure 2. Percentage frequency of total precipitation in Northwest Section

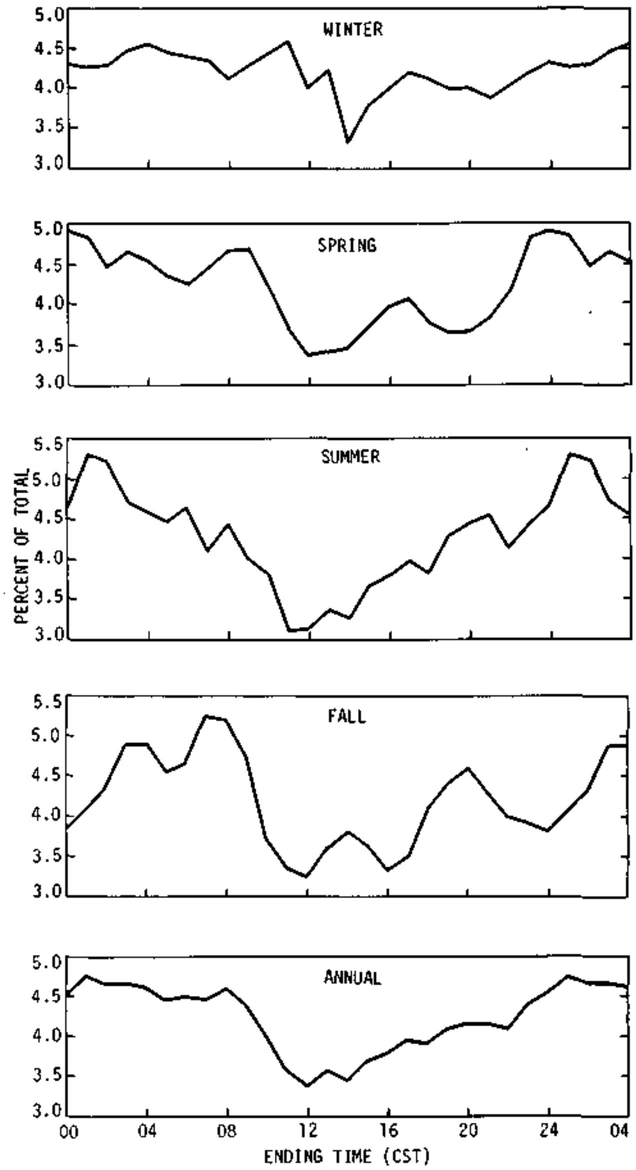

Figure 3. Percentage frequency of total precipitation in North Central Section

early morning hours, and a secondary peak in the late afternoon or early evening associated with diurnal heating effect on the production and/or intensification of rainfall. The Southeast Section has its primary maximum in mid-afternoon and some indication of a secondary peak in the distribution in the early forenoon.

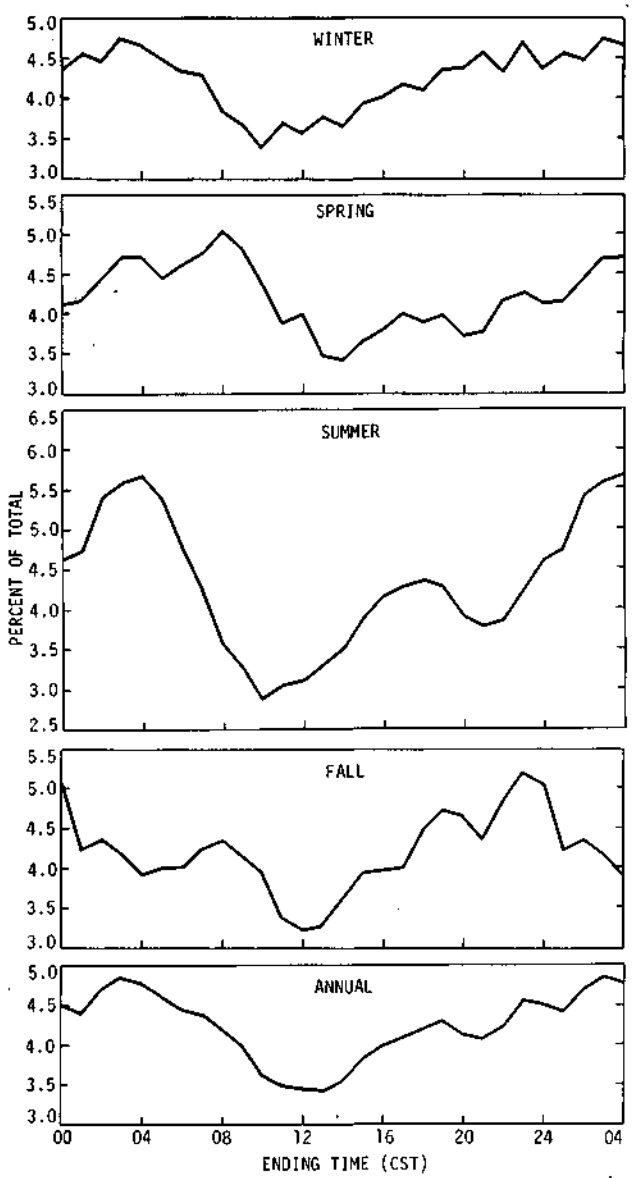

Figure 4. Percentage frequency of total precipitation in South Central Section

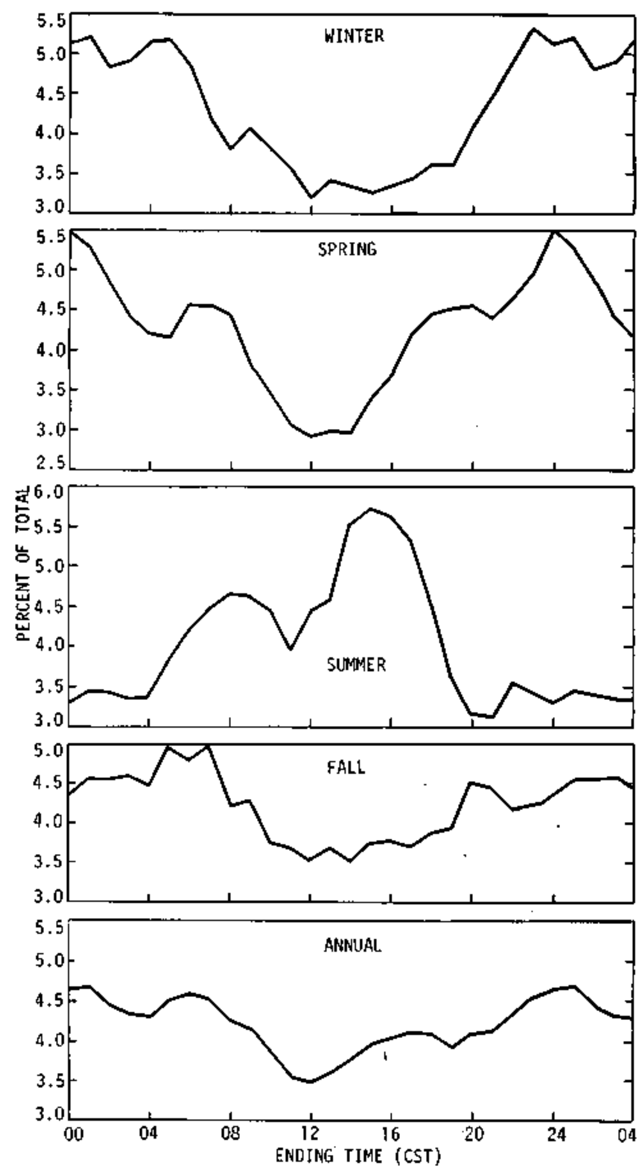

Figure 5. Percentage frequency of total precipitation in Southeast Section

The diurnal thunderstorm frequency (Changnon, 1968) in this section also peaks in the late afternoon. This variation in the occurrence of the primary maximum in the extreme southern part of the state suggests that daytime heating is a more important mechanism in the production of summer rainfall than in the other three regions. In turn, this suggests that air mass showers account for a greater portion of the summer rainfall in the extreme southern part of the state than in the other regions, in agreement with the findings of Hiser (1956). For example, Hiser found that 37 percent of the summer rainfall at Cairo at the southern tip of Illinois occurred as air mass showers, compared with 20 percent at Springfield in central Illinois, and 18 percent at Moline in the northwestern part of the state. Conversely, the early morning maximum in the other sections in summer indicates the importance of the nocturnal thunderstorm mechanism over most of the state, the nature of which is not fully understood. Although several theories have appeared in the literature pertaining to this phenomenon, none has had widespread acceptance.

The fall curves of figures 2-5 show the primary maximum in early morning in the Northwest, North Central, and Southeast Sections, and in late evening in the South Central Section, all of which agrees with the maximums in thunderstorm activity (Changnon, 1968). Indication of an early evening secondary peak, associated with diurnal heating, is present in all except the Northwest Section which is exposed least frequently to moist, convectively unstable, maritime tropical air in fall.

Daytime heating and the unexplained nocturnal thunderstorm phenomenon may account for the diurnal maximum of total rainfall in summer in the four sections, but these factors do not adequately account for the distribution in other seasons. Nocturnal thunderstorms are relatively frequent in fall, winter, and spring (Changnon, 1968), although thunderstorms are rare in winter in the northern half of the state (Changnon, 1957). This condition helps explain the night and early morning maximization in all four sections in. spring, fall, and winter. A more detailed explanation for the time distribution of the precipitation maximum will be presented later in this report.

<u>Frequency of Hourly Precipitation</u>

Figures 6-9 show the diurnal distribution of the number of hours with measurable precipitation in each of the four climatological sections on a seasonal basis. Mean rate distributions also shown on figures 6-9 will be discussed later.

The seasonal curves for the diurnal distribution of precipitation occurrences show similar winter relationships in the Northwest and North Central Sections.

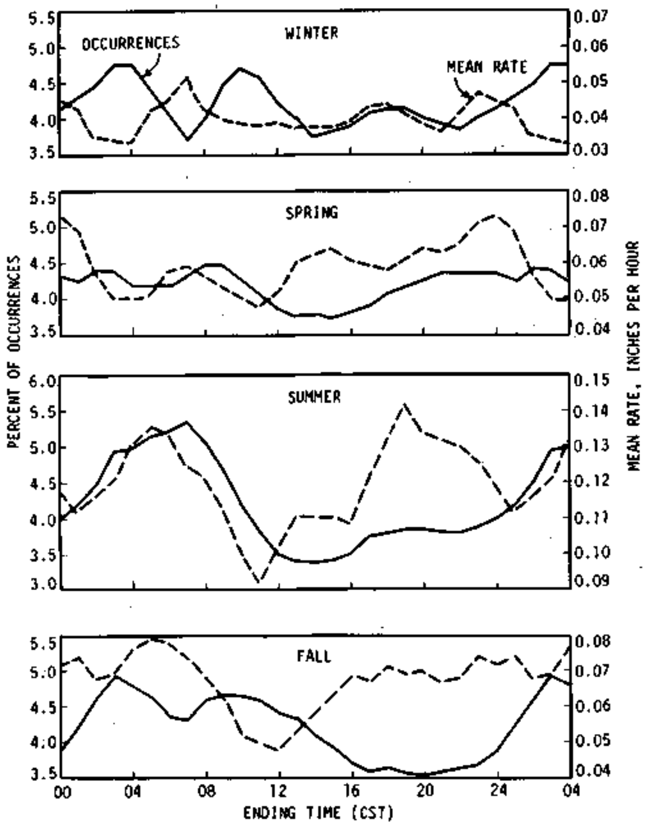

Figure 6. Percentage frequency of measurable precipitation occurrences and mean precipitation rate in Northwest Section

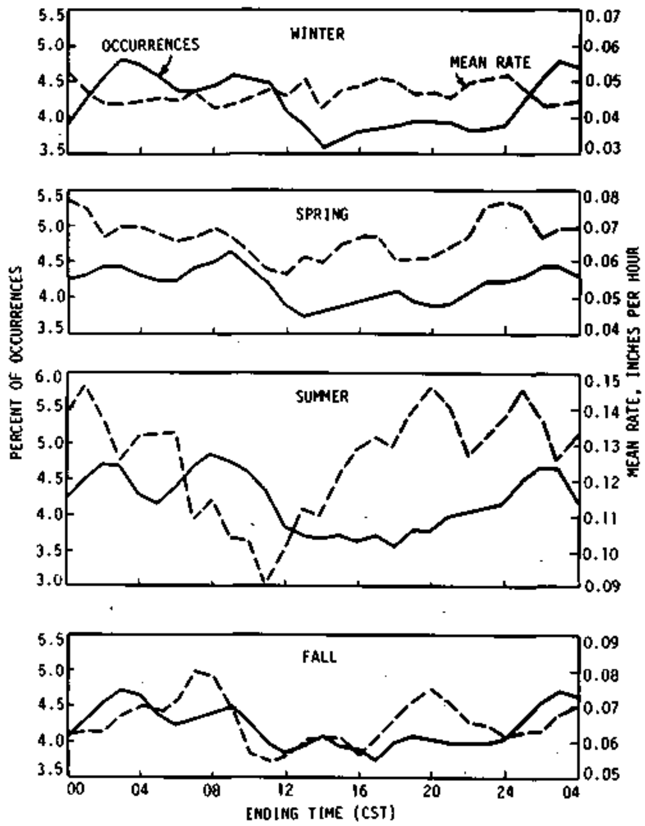

Figure 7. Percentage frequency of measurable precipitation occurrences and mean precipitation rate in North Central Section

These regions show a primary maximum in early morning, a secondary maximum in mid-forenoon, and a minimum in early afternoon. The South Central and Southeast Sections do not show the pronounced secondary maximum in mid-forenoon, otherwise they are similar to the other two sections in winter.

In spring, the primary minimum again occurs in early afternoon in all four sections. Except for reversal of the primary and secondary maximum, the winter and spring curves are very similar in the Northwest and North Central Sections. In the other two sections the primary maximum is in early morning, similar to the winter distribution, but there is indication of a secondary maximum in mid-forenoon. In general, the curves for all four sections are quite similar in winter and spring with respect to diurnal trends.

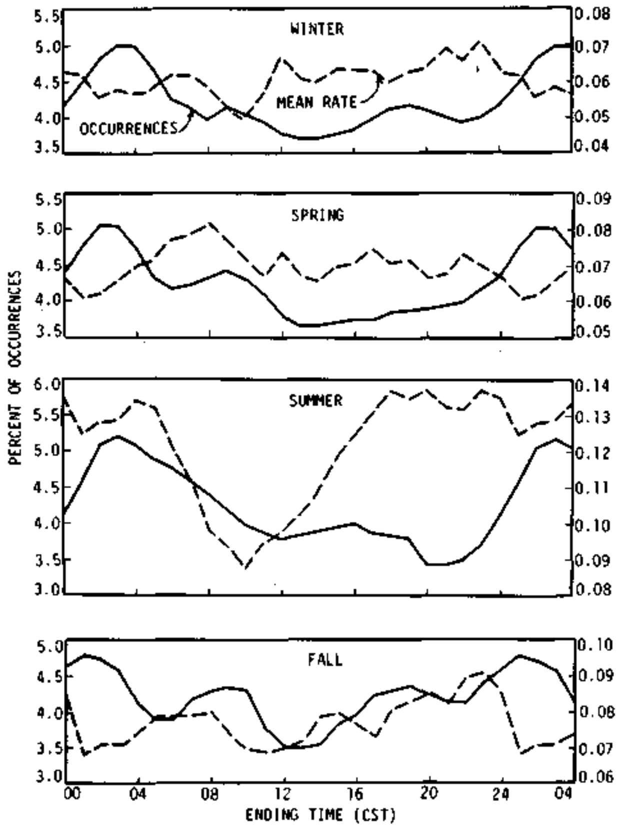

Figure 8. Percentage frequency of measurable precipitation occurrences and mean precipitation rate in South Central Section

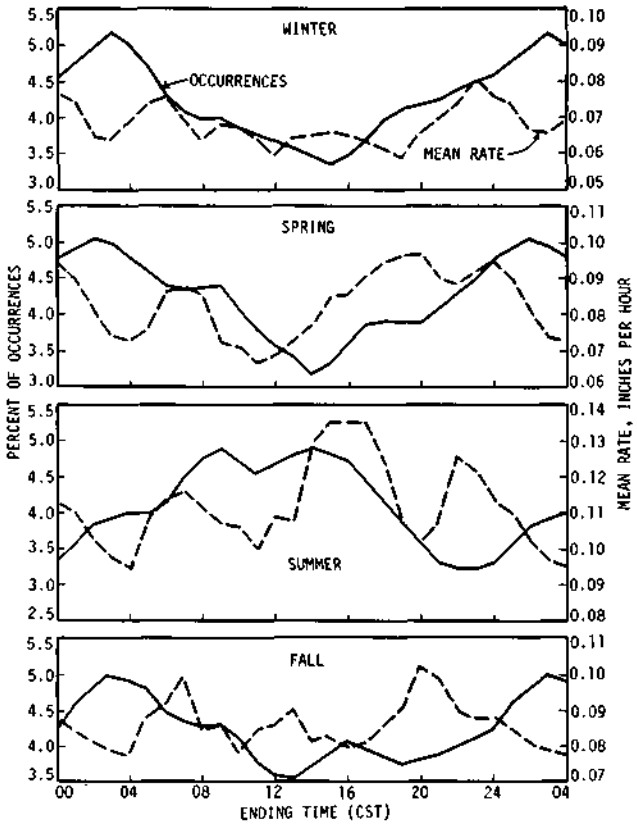

Figure 9. Percentage frequency of measurable precipitation occurrences and mean precipitation rate in Southeast Section

The summer curves show more dissimilarities between sections than the winter and spring distributions. In the Northwest Section, the primary minimum remains in early afternoon. The primary maximum occurs in early forenoon, and there is slight indication of a secondary maximum in the early evening, associated with the diurnal heating effect. In the North Central Section, the minimum occurs from early afternoon to early evening. The primary maximum occurs about 0800 CST, and there is a secondary maximum a few hours earlier at 0200 to 0300 CST. The diurnal heating maximum of late afternoon to early evening is not shown on this curve, and suggests this mechanism is of relatively small importance in determining the number of occurrences of summer rainfall in the North Central Section.

In the South Central Section in summer, the diurnal heating effect becomes more pronounced, and results in the destruction of the major afternoon minimum indicated in the two northern sections. Here, the primary minimum is displaced to evening with a secondary minimum near noon. The major maximum is in the early morning near 0300 CST, and a minor peak in the distribution is indicated at 1600 CST. In the Southeast Section, rainfall occurs most frequently in summer from early forenoon to late afternoon, and minimum frequencies are experienced in the late evening. The high frequency in afternoon is apparently associated with the diurnal heating mechanism, which appears to increase in importance southward throughout the state in summer. Summer thunderstorms in this section are most frequent between 1400 and 1800 CST (Changnon, 1968). The evening minimum in the two southerly sections may be related to the dissipation of thermal-induced afternoon showers and stabilization of the lower atmosphere from the rain process.

In fall, precipitation occurs most frequently from early morning to mid-forenoon in the Northwest Section and least frequently in the late afternoon and evening hours (figure 6). In the North Central Section, the minimum shifts to mid-afternoon, and the maximum is still from early morning to mid-forenoon, both similar to the thunderstorm diurnal distribution (Changnon, 1968). In the South Central and Southeast Sections, the fall minimum occurs in early afternoon. The South Central maximum is similar to those indicated for the two northern sections. The Southeast maximum is centered near 0300 CST. The fall and winter curves are quite similar in all four sections with respect to diurnal trends.

The diurnal effect upon the frequency of precipitation, as indicated by actual and percentage differences between curve maximums and minimums, is greatest in winter in the Southeast Section and shifts to the Northwest Section in summer. The nocturnal thunderstorm phenomenon is more pronounced in the Northwest Section in summer than in the other three sections (45 percent of all thunderstorms occur between 2200 and 0600 CST), and may be primarily responsible for the greater diurnal range in the number of rainy hours. The frequency of frontal passages (Chiang, 1961) and of convective precipitation increases southward in the state in winter, and may be related to the more pronounced diurnal range in southern Illinois in that season. On an annual basis, the diurnal range is most pronounced in the Southeast Section.

Summarizing, a tendency for precipitation to occur most frequently from early morning to mid-forenoon exists in Illinois in winter, spring, and fall seasons. Similarly, minimum frequencies tend to occur from late forenoon to late afternoon in these seasons with the mode of the distribution in early afternoon. In the summer, the diurnal heating influence is greatest and produces large changes in the diurnal distribution in the South Central and Southeast Sections. In these two sections, the diurnal minimum shifts to evening, and a major maximum appears in afternoon in the Southeast Section. Figures 6-9 imply that diurnal heating is most influential in the development of showers and thunderstorms in the extreme southern part of the state, and the thermal heating effect, in general, decreases northward in its relative importance. Its influence is reflected least in the diurnal statistics for the North Central Section.

Intensity of Hourly Precipitation

Table 3 shows the frequency of occurrence of hourly precipitation of various intensity for each of the four sections on a percentage basis for 3"hour periods throughout the day. The primary purpose of this analysis was to determine whether hourly precipitation has a tendency to be heavier at certain hours of the day.

Table 3 indicates that light rainfall (0.01-0.10 inch per hour) accounts for most of the precipitation hours in all sections and all times of the day, but is most dominant in late forenoon and early afternoon. Moderate hourly amounts (0.11-0.25 inch) have their highest percentage of the total in the early morning from 0300 to 0900 CST. Moderately heavy amounts (0.26-0.50 inch per hour) exert their greatest influence on the distribution in the late afternoon and early evening from 1500-2100 CST, except in the Northwest Section where 2100-2400 CST is most important. The heaviest amounts, those exceeding 0.50 inch per hour, have their highest percentages in early to late evening (1800-2400 CST), except in the South Central Section where it is late afternoon to early evening (1500-2100 CST). In general, the distributions show that a higher percentage of the precipitation hours have heavy intensities in the late afternoon and evening than at other periods of the day. Thus, the heavier intensities tend to occur during and following the period when the diurnal heating influence is greatest.

Mean Hourly Rates

In a further effort to evaluate the intensity factor in the diurnal distribution, mean hourly rates were computed by dividing the total precipitation recorded

Table 3. Percentage Frequency of Hourly Precipitation of Various Intensities

Period (CST)	0.01-0.10	0.11-0.25	0.26-0.50	0.51-1.00	Over 1.00
	Percent of total occurrences for given hourly amounts (*inches*)				
Northwest Section					
00-03	83.8	11.1	3.6	1.1	0.4
03-06	83.0	11.3	3.8	1.4	0.5
06-09	83.0	12.7	2.8	1.1	0.4
09-12	88.4	9.2	1.8	0.4	0.2
12-15	86.8	9.2	2.6	1.1	0.3
15-18	85.3	10.2	2.7	1.2	0.6
18-21	83.7	10.8	3.4	1.6	0.5
21-24	81.5	12.4	4.2	1.6	0.3
North Central Section					
00-03	82.7	11.4	4.1	1.6	0.2
03-06	81.9	12.9	3.7	1.3	0.2
06-09	83.8	11.5	3.3	1.1	0.3
09-12	86.9	9.3	2.5	1.1	0.2
12-15	85.8	9.9	3.1	1.0	0.2
15-18	83.7	10.6	3.8	1.4	0.5
18-21	82.2	11.1	4.3	1.9	0.5
21-24	81.9	12.0	4.1	1.5	0.5
South Central Section					
00-03	81.3	13.3	3.6	1.5	0.3
03-06	78.2	16.0	4.1	1.2	0.5
06-09	80.2	13.6	4.5	1.2	0.5
09-12	83.0	13.0	2.5	0.9	0.6
12-15	82.1	12.4	3.6	1.5	0.4
15-18	80.1	12.3	4.9	2.2	0.5
18-21	79.9	13.0	4.8	2.0	0.3
21-24	77.8	15.0	4.6	2.1	0.5
Southeast Section					
00-03	79.0	14.3	4.9	1.8	0.2
03-06	77.3	15.9	5.3	1.3	0.2
06-09	77.2	16.5	4.9	1.2	0.2
09-12	78.0	15.6	4.6	1.3	0.5
12-15	79.4	13.0	5.0	2.0	0.6
15-18	78.7	13.2	5.8	1.8	0.5
18-21	77.2	15.3	5.0	1.6	0.3
21-24	76.8	15.2	4.7	2.8	0.5

during each hour of the day by the number of hours with measurable precipitation during the 10-year sampling period. These rates were determined for each section on a seasonal basis. The percentage distributions of hourly mean rates are shown in figures 6-9.

The diurnal curves of mean rate for winter are relatively flat except in the Southeast Section, where late evening and early forenoon maximums are shown. In spring, the average hourly rate is highest near midnight in the North Central and Northwest Sections, shifts to early forenoon in the South Central Section, and occurs during the evening hours in the Southeast Section. The general trend in the state is for a night maximization of the average precipitation rate in spring and minimization near noon.

The summer mean rate curves show the lowest rates in late forenoon in all four sections. The Southeast Section shows a pronounced maximum in mid-afternoon, associated with the diurnal heating effect. The major afternoon peaks in the distributions of total rainfall, frequency of measurable rainfall, and mean rainfall rate for summer in the Southeast Section (figures 5 and 9) indicate that diurnal heating has a strong influence on both the development and intensification of showers and thunderstorms in this region.

The South Central Section in summer shows a pronounced peak in the mean rate distribution which begins in the late afternoon and extends throughout the night. The early morning maximum of mean rate in this section corresponds to maximums about the same time in the curves of total precipitation and frequency of measurable precipitation (figures 4 and 8), and indicates the presence of a strong nocturnal influence on the development and intensification of storms. The maximum 8-hour period of summer thunderstorm activity in the area begins at 2000 CST (Changnon, 1968). The late afternoon and early evening peak in the South Central distribution is related to the diurnal heating influence. The degree of peakedness in the curves suggests that the diurnal effect is felt more in the intensification of rainstorms than in the development of showers in this area.

The North Central Section has peaks in the mean rate distribution at 0100 and 2000 CST in summer. The maximum at 0100 CST is a nocturnal phenomenon which is reflected in the diurnal distributions of total precipitation and frequency of measurable precipitation. The maximum at 2000 CST is apparently associated with intensification of showers by diurnal heating. As noted earlier, the diurnal heating effect is not shown in the summer curve for frequency of rainfall occurrences. However, the effect is reflected in the curves of total rainfall and rainfall rate (figures 3 and 7), and suggests that diurnal heating has little effect upon the development of summer rainstorms in this region, but that it does frequently result in intensification of existing storms.

In the Northwest Section in summer, peaks occur in the mean rate distribution at approximately 0500 and 1900 CST, the evening peak being slightly greater than the early morning maximum. The pronounced evening peak in mean rate and the very slight indication of an evening peak in the curve of rainfall occurrences (figure 6) indicate that the diurnal heating influence is reflected mostly in the intensification of summer rainstorms, rather than in the development of showers. A pronounced nocturnal thunderstorm mechanism is indicated by the early morning maximum which is similar to those found in the North Central and South Central Sections, and which is indicated to a lesser extent by an early forenoon peak in the curve for the Southeast Section.

Relation between Fronts and Diurnal Precipitation Distribution

In the preceding studies of diurnal distributions, the presence of a nocturnal mechanism which results in maximization of the diurnal curves at night or in the early forenoon has been noted. As indicated earlier, this phenomenon is present throughout the year, and is the dominant feature of the curves in most cases.

A possible cause of the night and early morning maximums could be the diurnal distribution of fronts, if a tendency exists for them to approach and pass through Illinois more often at night than in the daytime. Huff (1961) reported a strong association between the diurnal frequency of frontal passages at Urbana, Illinois, and the diurnal maximization of precipitation. The Urbana relation is illustrated in figure 10, where the diurnal distribution of all fronts combined is shown in conjunction with the diurnal distribution of the occurrence of measurable precipitation in the North Central Section, in which Urbana is located. The frontal curve (data for 1951-1960) is based upon 3"hour moving totals, which were used to smooth the sampling fluctuations inherent in the single station sample.

Except for winter, the frontal and precipitation curves compare favorably with respect to major maximums and minimums in the diurnal distribution. Even in winter, the general trend of higher values is quite similar; for example, both curves have

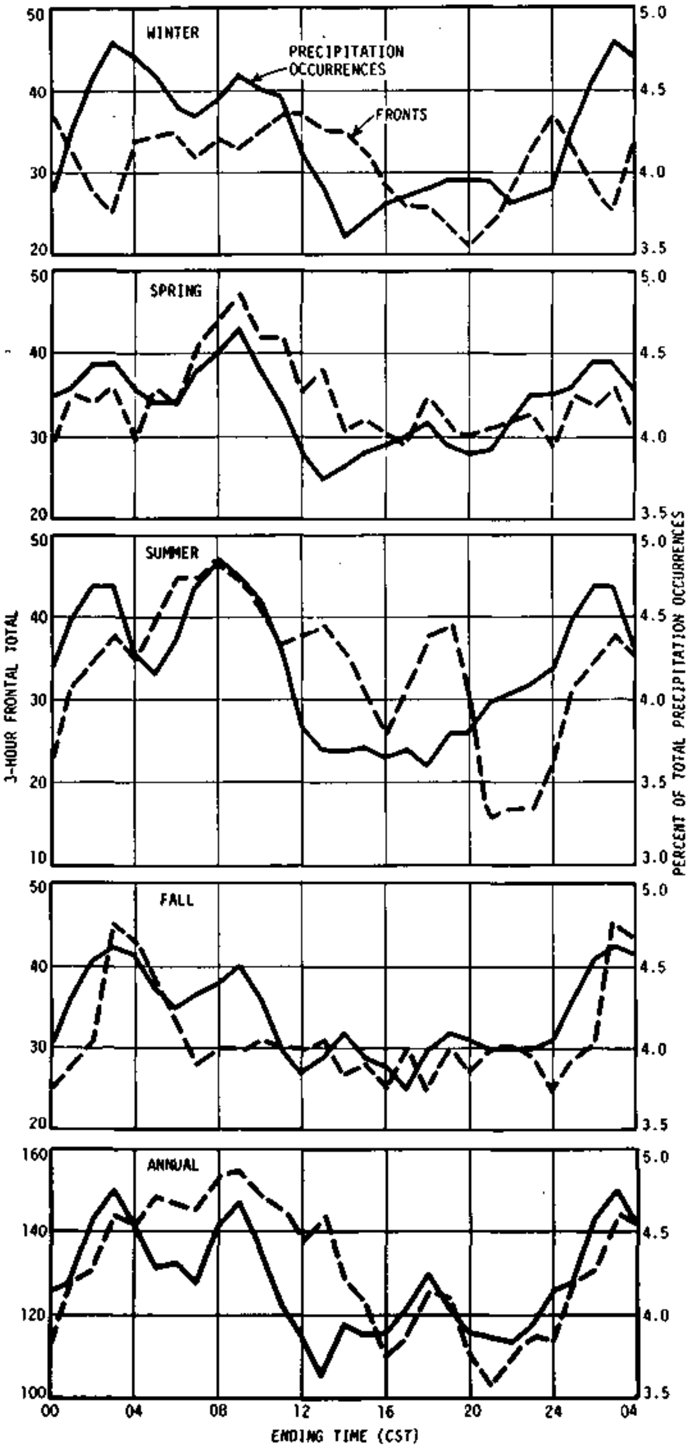

Figure 10. Comparison of Urbana frontal distributions with distribution of hourly precipitation occurrences in North Central Section

their highest values from midnight to noon. The annual curve, which combines all the data, shows excellent correspondence between the maximums and minimums of fronts and precipitation. If the Urbana relation is representative of relations throughout the state, it appears that the diurnal maximization of precipitation can be attributed to three factors, the nocturnal thunderstorm mechanism, the frontal distributions, and the diurnal heating effect. The frontal distributions and nocturnal thunderstorm mechanism may account largely for the night and early morning maximums and daytime heating for the afternoon and early evening maximums.

Diurnal Distribution of Severe Rainstorms

Huff and Semonin (1960) made a study of the most severe rainstorms in Illinois during the period 1948-1958. Their study contained 13 storms with durations of 2k hours or less. Among these storms, the 3-hour period of maximum rainfall occurred most frequently in the period from 0000 to 0600 CST, and the 6-hour maximum occurred most frequently in the period from 0000 to 0900 CST. Reference to the annual curves of figures 2-5 show excellent correlation between the climatological maximization of total precipitation and the maximization of severe rainstorms. Figures 2-5 indicate that the 3-hour period of heaviest precipitation is 0400-0700 CST in the Northwest, 0000-0300 CST in the North Central, 0100-0400 CST in the South Central, and 2200-0100 CST in the Southeast Section. Maximum 6-hour periods on the curves of figures 2-5 are 0200-0800 CST in the Northwest and North Central, 2300-0500 CST in the South Central, and 2100-0300 CST in the Southeast Section.

Huff and Semonin also state that the 3-hour period of heaviest rainfall in the 13 storms with durations of *2k* hours or less occurred in all cases between 1800 and 0630 CST, with 77 percent between 2100 and 0600 CST. All 6-hour maximums occurred between 1800 and 0900 CST. When storms up to 48 hours in duration were included, a sample of 28 severe rainstorms was obtained for the 1948-1958 period. Of these 28 storms, *2k* had their 6-hour period of heaviest rainfall between 1800 and 0900 CST.

This preponderance in maximization of severe rainstorms during the night and early morning hours may be due to the presence of two maximizing factors, one operating in the afternoon and early evening and the other during the night. Other factors being equal, storms will tend to develop and intensify during the afternoon and early evening hours from the influence of the diurnal heating effect. This effect is most pronounced in the warm season, when most of the severe rainstorms occur. As the evening progresses, the storm systems (convective systems) which developed and intensified during the diurnal heating period become subjected to a nocturnal intensifying mechanism that gradually increases in intensity into the morning hours, according to the results of our study of the diurnal distribution of precipitation.

Storm maximization of exceptionally heavy storms in the late evening and early morning hours appears to result from exposure of existing convective systems to both intensifying mechanisms. Detailed studies of 10 storms in which 10 inches or more of rainfall occurred at the storm center (Huff et al., 1958; Huff and Changnon, 1961) showed convective systems within or approaching the storm region during the afternoon and/or early evening preceding the initiation and maximization of the severe rainstorms. In 8 of the 10 cases, the convection system identified with the storm initiation had developed in or moved into the rainstorm zone by late afternoon or early evening. In the other two cases, heavy rainfall did not occur until near midnight, but squall line activity was present in the vicinity during the afternoon and evening, and movement into the storm zone during the evening was indicated. Thus, the convection systems associated with the development of these 10 severe storms could have been exposed to both the afternoon and night intensifying mechanisms which influence Midwest storms.

Although strong correlation appears to exist between the nocturnal maximization of precipitation, thunderstorms, and severe rainstorms, other severe weather phenomena are more closely related to the daytime heating influence. Huff and Changnon (1959) found that the most frequent 3-hour period of hail in Illinois is from 1430 to 1730 CST and the most frequent 6-hour period is from 1330 to 1930 CST. Tornadoes occur most frequently from 1400 to 2000 CST, according to the study of Wilson and Changnon (1971).

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